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ScienceDirect
Aquacultural Engineering 37 (2007) 73–78
aquacultural engineering
www.elsevier.com/locate/aqua-online

Review

Influence of water salinity on the SOTR of paddlewheel and propeller-aspirator-pump aerators, its relation to the number of aerators per hectare and electricity costs

Luis Vinatea *, José W. Carvalho

Laboratório de Camarões Marinhos, Departamento de Aqüicultura, CCA, Universidade Federal de Santa Catarina, 88.040-900, Florianópolis, SC, Brazil

Received 16 August 2006; accepted 1 February 2007

Abstract

The objective of this study was to determine the standard oxygen transfer rate (SOTR) (kg O_2/h) of 2-HP (1.49 kW) paddlewheel (PW) and propeller-aspirator-pump (PAP) aerators submitted to salinities of 0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55 and 60‰. Tests were carried out in round 50 m^3 tanks. SOTR of paddlewheel and propeller-aspirator-pump aerators was maximum (3.79 ± 0.30 and 3.62 ± 0.04 kg O_2/h, respectively) at salinity 30‰. Above 30‰, efficiency of aerators was slightly reduced. These results suggest that it is possible to calculate the number of aerators according to the salinity of the culture ponds and, consequently, predict electricity costs.

Keywords: SOTR; Dissolved oxygen; Salinity; Aerators

Contents

1. Introduction

Aerators are essential in semi-intensive and intensive aquaculture to maintain the environment appropriate to the physiological requirements of cultured organisms. Furthermore, water dissolved oxygen concentration and availability are critical to their health and survival. Reduced oxygen concentration due to accumulation of organic matter in pond bottom soils can increase susceptibility to diseases by impairment of the immune system (Wootten, 1998; Mikulski et al., 2000; Kautsky et al., 2000; Jiang et al., 2004).

According to Boyd (1990), the ability of aerators to transfer oxygen into the water can be determined by the

* Corresponding author. Tel.: +51 48 32313400.
E-mail address: vinatea@mbox1.ufsc.br (L. Vinatea).

0144-8609/$ – see front matter
doi:10.1016/j.aquaeng.2007.02.001

standard oxygen transfer rate (SOTR) and by the standard aerator efficiency (SAE). SOTR (kg O_2/h) is the amount of oxygen that a mechanical aerator is capable of transferring in 1 h into clean, zero dissolved oxygen water at 20 °C. SAE (kg O_2/kWh) expresses the aerator's efficiency and it is the result of the division of the SOTR by the energy consumption unit (kW).

Gas solubility in water decreases with increased salinity and temperature (Boyd, 1998). Nevertheless, opposite to what would be expected for seawater and brackish water, Fast et al. (1999) reported a 46% SAE increase in 1-HP aerators tested at 11‰, and 67% when engine power was reduced to half. Nunes (2002) and Fast et al. (1999) report that the oxygen transfer rates of paddlewheel aerators practically doubled at every increase of 10‰ in salinity, possibly due to the lower amount of oxygen required to reach saturation or to the presence of dissolved salts, which would influence water superficial tension with consequent change in air bubble size in the water (Boyd and Tucker, 1998).

More precise information is required about the performance of aerators in different salinities to define equipment management plans according to their power efficiency. In marine shrimp farms, for example, variable costs of electricity with aerators represent about 15% of the production cost (Seiffert, personal communication). As for operational costs, electricity expenses due to aeration appear on third, after artificial feed and post larvae costs (Ayres, cited by Igarashi et al., 2000).

The objective of this study was to determine the SOTR for 2-HP paddlewheel and propeller-aspirator-pump aerators in salinities ranging from 0 to 60‰ and then try to improve the estimation of the required number of aerators per hectare and electricity costs.

2. Materials and methods

The study was carried out at the facilities of an aerator manufacturer company (Bernauer Aquacultura Ltda., Blumenau, SC, Brazil). Circular galvanized test tanks covered with dark plastic sheet, with 6.4 m diameter and 50 m^3 effective capacity (1.5 m depth) were used. Paddlewheel aerators (Aquapá B-209 model) (Fig. 1) with eight rotors of five rotating paddles each, and propeller-aspirator-pump aerators (B-203 model) (Fig. 2), both made by the company, were fixed in the center of the tanks. Aerators had the same engine power (2-HP, 1.49 kW), connected to a 380 V (60 Hz) three-phase electric service.

Freshwater (0‰ salinity) was obtained from mineral spring wells (São Lucas wells, Indaial, SC) and taken to

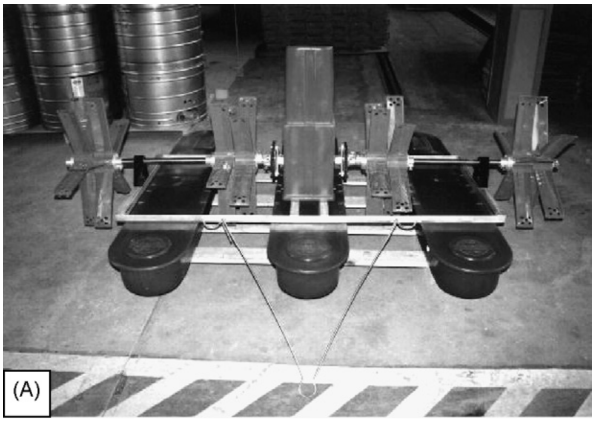

Fig. 1. (A) 2-HP paddlewheel aerator (model Aquapá B-209) with eight rotors of five rotating paddles and (B) the Aquapá B-209 aerator in operation.

the test site on tanker trucks. This water source was used to prepare all the salinities of this study by adding iodine-free marine salt (99.8% NaCl and 0.2% H_2O, Ca, Mg, SO_4). Marine salt was previously dissolved in 1000 L water tanks with the aid of a 1-HP submersible pump. After each test, water was discharged and sent to an outdoor saltwater pond. Oxygen concentration was measured several times (*n* 10) during the tests at 30, 50, 60 and 90 cm water depths.

SOTR of each aerator model was determined in triplicate per salinity. Previously, aerators were tested in salinities 0 and 5‰ to determine variation coefficient.

Sodium sulfite (Na_2SO_3) was used to deplete oxygen from water at the proportion of 10 mg/1 mg of oxygen in 1 L of water, and cobalt chloride ($CoCl_2$) as catalyzer, in the proportion of 0.1 mg/L of water. These compounds were mixed in the test water tank with the aid of a submersible pump to completely dissolve and homogenize them.

Once all oxygen was depleted from the water, temperature was measured and aerators operated. Then,

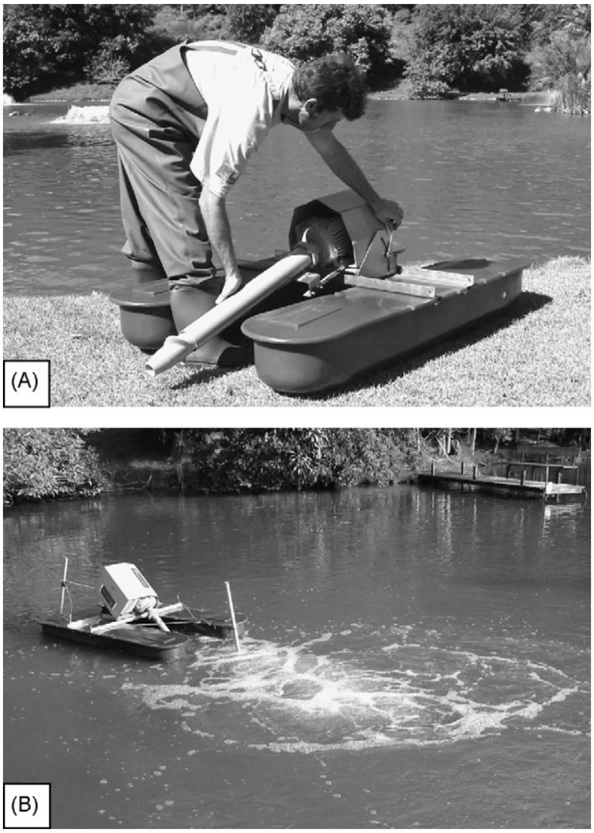

Fig. 2. (A) 2-HP propeller-aspirator-pump aerator (model Aquapá B-203) and (B) the Aquapá B-203 aerator in operation.

dissolved oxygen concentration was computed every 30 s with a digital oxygen meter (Handy gamma, Oxyguard®). Atmospheric pressure was also measured with a digital barometer. Salinity was measured with an optical salinometer (Aquafauna). Tests were stopped as soon as oxygen concentration was above 75% saturation.

SOTR and SAE were calculated with the equations used by Boyd (1990), based in American Society of Civil Engineers (ASCE) standard method for aerator evaluations.

Once the SOTR and SAE were determinate in each salinity, the number of aerators of two aerator models required for a hypothetic marine shrimp culture was simulated. For such, a total oxygen consumption of 1.16 mg O_2/L/h was considered, which refers to the summation of maximum shrimp respiration (0.16 mg O_2/L/h), according to Fast and Boyd (1992), and average water and sediment respiration rates of 0.5 mg O_2/L/h each, usually found in semi-intensive shrimp farms in Brazil (Vinatea and Beltrame, 2005).

Considering those values, total oxygen demand (TOD) per hectare with 1 m of deep (15,000 m^3), could then be calculated:

$$\mathrm{TOD} = \mathrm{OD} \times V \times 10^{-3} \quad (1)$$

where TOD is the total oxygen demand (kg/h), V the volume of the pond (m^3) and 10^{-3} is the conversion factor (kg/g).

Based on the SOTR for mechanical aerators obtained in different salinities, the oxygen transfer rate at 25 °C was determined as:

$$\mathrm{OTR}_t = \frac{\mathrm{SOTR}(C_s - C_m)}{C_s} \times 1.024^{(T-20)} \quad (2)$$

where, OTR_t is the oxygen transfer rate at 25 °C (kg O_2/h), SOTR the standard oxygen transfer rate (kg O_2/h) in salinities 0–60‰, C_s the saturated oxygen concentration at 20 °C (mg/L) in salinities 0–60‰ (Boyd, 1990) and C_m is the minimum tolerated oxygen concentration (50% of the oxygen saturation at 20 °C in salinities 0–60‰).

After calculations, aeration required per pond hectare (N/ha) was determined using the formula:

$$\text{Number of aerators} = \frac{\mathrm{TOD}}{\mathrm{OTR}_t} \quad (3)$$

To compare the oxygen concentrations measured in the different pond depths Student t-test ($P < 0.05$) was used. The same test was used to compare SOTR means in the different salinities. Aerators SOTR behavior in the different salinities was expressed by a polynomial regression analysis ($P < 0.05$).

3. Results and discussion

Aerators performance in aquaculture ponds is not always correlated to the SOTR values found in test tanks (Fast and Boyd, 1992), which contains only clean water without plants, animals or suspended matter. Since water oxygen concentration is affected by salinity, temperature, atmospheric pressure, organic matter, photosynthesis, and chemical and biological respiration, aerators SOTR can alter drastically (Hernandez and Nunes, 2001). On the other hand, depending on pond water and sediment respiration, the number of aerators per hectare can increase with pond aging (Dalla-Santa and Vinatea, 2007). Thus, a stronger aeration (more HP per hectare) does not necessarily guarantee a higher yield, because extrinsic (SOTR) and intrinsic (physico-chemical and biological variables) factors of the culture environment can lead to a miscalculation of the number of aerators per area (Vinatea and Beltrame, 2005).

Table 1
Mean (±standard deviation) SOTR (kg O_2/h) values of 2-HP paddlewheel and propeller-aspirator-pump aerators in different salinities and under atmospheric pressures of 1011–1015 mbar

Salinity (‰)	2-HP paddlewheel		2-HP propeller-aspirator-pump	
	SOTR (kg O_2/h)	Increase (%) in relation to 0‰	SOTR (kg O_2/h)	Increase (%) in relation to 0‰
0	2.20 ± 0.082 a	0.00	1.27 ± 0.051 b	0.00
5	2.27 ± 0.109 a	3.18	1.62 ± 0.046 b	27.56
10	2.69 ± 0.186 a	22.27	2.29 ± 0.032 b	80.31
15	3.70 ± 0.229 a	68.18	3.19 ± 0.434 b	151.18
20	3.70 ± 0.557 a	68.18	3.28 ± 0.269 b	158.27
25	3.75 ± 0.246 a	70.45	3.51 ± 0.101 a	176.38
30	3.79 ± 0.308 a	72.27	3.62 ± 0.044 b	185.04
35	3.66 ± 0.392 a	66.36	3.39 ± 0.359 a	166.93
40	3.48 ± 0.128 a	58.18	3.10 ± 0.194 a	144.09
45	3.46 ± 0.223 a	57.27	3.39 ± 0.211 a	166.93
50	3.29 ± 0.201 a	49.55	3.43 ± 0.095 a	170.08
55	2.99 ± 0.321 a	35.91	3.29 ± 0.299 a	159.06
60	2.92 ± 0.172 a	32.73	2.54 ± 0.208 b	100.00

Different letters indicate significant difference ($P < 0.05$) between the SOTR of each model of aerator in the same salinity.

A coefficient of variation (CV) of 4.3% was determined from tests with three replicates (three aerators of each model) in the salinities 0 and 5‰. That allowed the tests in the other salinities to be done only with one aerator of each model. Atmospheric pressure during the tests ranged from 1011 to 1015 mbar. Oxygen meter probe readings at 30, 50, 60 and 90 cm depths did not result in significant difference ($P > 0.05$) in relation to the SOTR values. That indicates that the circular shape and the depth of the tank allowed homogeneous distribution of the oxygen in the water.

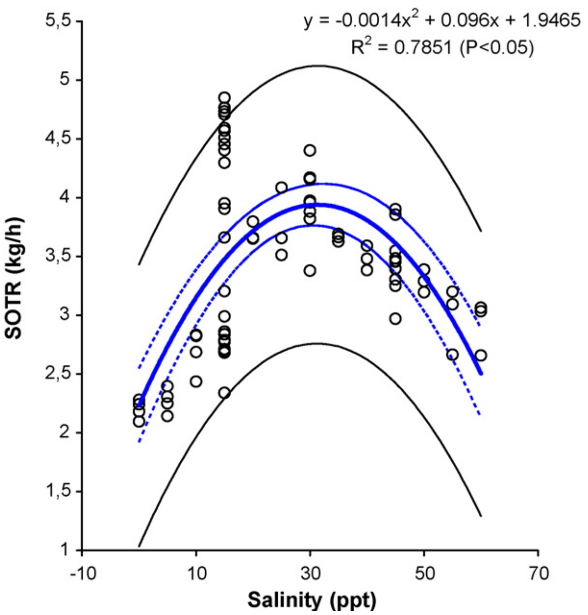

Fig. 3. Influence of water salinity on SOTR (kg O_2/h) of 2-HP (1.49 kW) paddlewheel aerators.

Aerators SOTR values increased with salinity (Table 1). Results in the tested salinities also demonstrate that the SOTR values were higher with paddlewheel aerators than with propeller-aspirator-pumps, as reported by other authors (Boyd and Daniels, 1987; Engle and Hatch, 1988; Boyd, 1990; Fast et al., 1999). However, SOTR increase rate in higher salinities was higher with propeller-aspirator-pump aerators. By using polynomial regression analyses, it was possible to obtain equations to predict SOTR for both models of aerators in salinities 0–60‰ (Figs. 3 and 4). Nevertheless, it should be kept in mind that such equations are valid only for the models, engine power and brand tested in this study.

Propeller-aspirator-pump aerators showed increasing performance starting from salinity 5‰ (27.5%), whereas the paddlewheel aerators showed higher performance (22.2%) from salinity 10‰. Maximum SOTR values of 72.2 and 185.0% for paddlewheel and propeller-aspirator-pump, respectively, were found in salinity 30‰. This result differs from that found by Fast et al. (1999), who reported that the paddlewheel efficiency increased 67% in salinity 11‰, but such efficiency was not so significant in salinity 22‰. This difference may be due to the distinct design and power of the aerators tested.

Based on our results, it is possible to presume that in freshwater or in low salinity waters the aerators will operate for more time to ensure enough dissolved oxygen to meet the requirements of the cultured

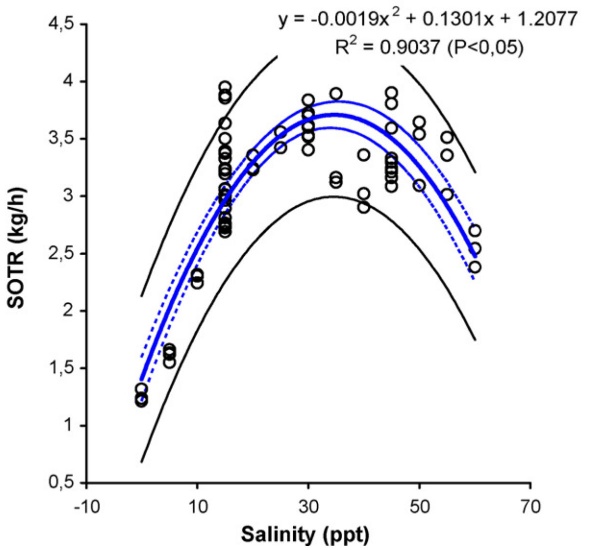

Fig. 4. Influence of water salinity on SOTR (kg O_2/h) of 2-HP (1.49 kW) propeller-aspirator-pump aerators.

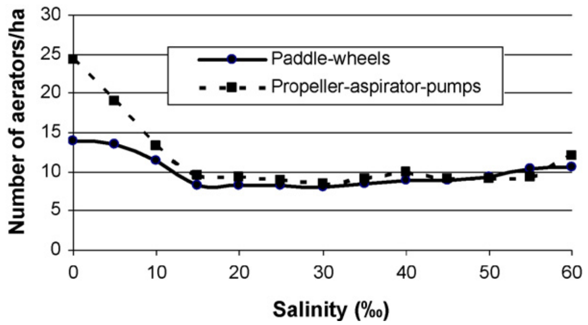

Fig. 5. Number of 2-HP (1.49 kW) paddlewheel and propeller-aspirator-pump aerators required per hectare according to water salinity.

organisms. This can result in increased production costs due to high electricity consumption to maintain the aerators operating and because more aerators will be necessary per hectare.

As mentioned previously, to demonstrate the impact water salinity has on operational costs in an aquaculture farm (marine shrimp farm, for example), the number of aerators per hectare was simulated considering oxygen consumption of 1.16 mg O_2/L/h and SOTR resulting from each salinity (Table 1). Number of aerators in such conditions, for each type of aerator in all salinities can be seen in Fig. 5. Table 2 shows the costs with electricity in all salinities tested considering average of US$ 0.08/kWh and 8 h of daily operation.

Paddlewheel aerators were shown to be more economic than the propeller-aspirator-pumps as regards to electricity costs in salinities between 0 and 10‰; in salinities above 15‰ there is no difference between the number of aerators required per hectare for each model. On the other hand, in salinities 50 and 55‰ the propeller-aspirator-pump aerators performed slightly better than the paddlewheels, which may be due to experimental error or physico-chemical factors not included in this study.

These results allow us to conclude that water salinity influences SOTR and SAE of paddlewheel and propeller-aspirator-pump aerators. In salinity 30‰, it is possible to obtain maximum SOTR and SAE for both models. Furthermore, water salinity influences indirectly the number of aerators per hectare and electricity costs.

Table 2
Number of aerators per hectare (*N*/ha), SAE (kg O_2/kWh), cost of 1 kg of oxygen (US$/kg O_2), monthly cost with electricity per hectare (US$/ha/month) and difference in the electricity costs (PAP−PW) between paddlewheel (PW) and propeller-aspirator-pump (PAP) aerators in salinities between 0 and 60‰, considering oxygen consumption of 1.16 kg O_2/L/h, 15,000 m^3, aerators operation of 8 h/day, minimum of 50% saturation and electricity cost of US$ 0.08 kWh^{-1}

Salinity (‰)	*N*/ha (PW)	*N*/ha (PAP)	SAE (PW)	SAE (PAP)	US$/kg O_2 (PW)	US$/kg O_2 (PAP)	US$/ha/month (PW)	US$/ha/month (PAP)	PAP−PW (US$/ha/month)
0	14.0	24.3	1.46	0.84	0.054	0.094	403.2	699.8	296.6
5	13.6	19.0	1.51	1.08	0.052	0.074	391.6	547.2	155.5
10	11.4	13.4	1.79	1.52	0.044	0.052	328.3	385.9	57.6
15	8.3	9.6	2.46	2.12	0.032	0.037	239.0	276.4	37.4
20	8.3	9.4	2.46	2.18	0.032	0.036	239.0	270.7	31.6
25	8.2	8.8	2.50	2.34	0.032	0.034	236.1	253.4	17.2
30	8.1	8.5	2.52	2.41	0.031	0.033	233.2	244.8	11.5
35	8.4	9.1	2.44	2.26	0.032	0.035	241.9	262.0	20.1
40	8.8	9.9	2.32	2.06	0.034	0.038	253.4	285.1	31.6
45	8.9	9.1	2.30	2.26	0.034	0.035	256.3	262.0	5.7
50	9.3	9.0	2.19	2.28	0.036	0.034	267.8	259.2	−8.6
55	10.3	9.3	1.99	2.19	0.040	0.036	296.6	267.8	−28.8
60	10.5	12.1	1.94	1.69	0.041	0.047	302.4	348.4	46.0

Acknowledgements

The authors wish to thank Klaus Bernauer and Cláudio Tessarolo, from Bernauer Aquacultura Ltda., SC, Brazil, for their support during this study; the Graduate Program in Aquaculture, Universidade Federal de Santa Catarina for offering multiple opportunities; Prof. Antonio Ostrensky and Alex Pires de Oliveira Nuñer, for their very important suggestions.

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